

PROCEEDINGS AND FINDINGS OF THE 1976 WORKSHOP ON RIDE QUALITY

**1976 WORKSHOP ON RIDE QUALITY
LAKE MOREY INN, FAIRLEE, VERMONT
OCTOBER 13-15, 1976**



NASA

National Aeronautics and
Space Administration

Langley Research Center

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1976 WORKSHOP ON VEHICLE RIDE QUALITY

Conducted by:

Task Force on Ride Quality (A3B51)
Transportation Research Board

at

Lake Morey Inn
Fairlee, Vermont

October 13-15, 1976

Summary Report

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PREFACE

As editor, I should like to exercise my prerogative to intrude at this point to express my sincere appreciation to all of my friends and colleagues whose efforts made this workshop successful and this report possible. I refer to the group leaders and group recorders whose names appear in Appendix B, and to Mrs. Ann Symmers, who was responsible for the general arrangements and the efficient management of the meeting. Also, I want to express the gratitude of all the participants for the extra effort made by John J. Fearnside of the Office of the Secretary, U.S. Department of Transportation, by John P. Jankovich of the Transportation Systems Center, U.S. Department of Transportation, by Ira D. Jacobson of the University of Virginia, and by Michael J. Clarke of the University College of Swansea in making special presentations to us during our evening sessions.

The workshop was funded by the Department of Transportation (DOT) through the Transportation Advanced Research Projects program. The assistance of the DOT Transportation Systems Center (Cambridge, Mass.) and NASA Langley Research Center are gratefully acknowledged.

Finally, I want to emphasize that the reports of the specific groups which follow are primarily the work of the recorders for those groups. A draft of each report was circulated among all participants of each group for comment. The comments received were reviewed by the editor and utilized as he deemed appropriate, often in consultation with the recorder. Although a general format for preparing the group reports was suggested, no effort has been made in editing to force them into some particular style. Thus they remain essentially as the creation of the particular recorder involved.

A. R. Kuhlthau
Charlottesville, Virginia
11/15/76

BACKGROUND AND OBJECTIVES

The workshop, held at the Lake Morey Inn, Fairlee, Vermont, was organized and conducted by the Task Force on Ride Quality (A3B51) of the Transportation Research Board (TRB), with the support of the U.S. Department of Transportation (DOT), through the Transportation Advanced Research Projects program, and with the assistance of the NASA Langley Research Center (NASA).

The Task Force on Ride Quality was established by the Transportation Research Board in June 1975 to examine the ride-quality technology needs of the entire transportation community and advise TRB by January of 1977 on the need for a continuing body in the area of ride quality.

In August of 1975 the members of the Task Force (see Appendix A) participated in a symposium and workshop on ride quality held in Williamsburg, Virginia, under the joint supervision of DOT and NASA. The workshop sessions focused on a definition of the state-of-the-art in current understanding of the major factors involved in ride quality.¹ It was agreed at that time that it would be of value to hold a second workshop to relate the current knowledge to the needs in several key areas of the ride-quality system and thus identify the major technology gaps which now exist.

Thus the Task Force agreed to organize the 1976 workshop,² deciding on a format of four basic working groups as described in the next section. Each working group was charged with the following responsibilities in its area of concern:

¹Summary Report of 1975 Workshop on Vehicle Ride Quality.

²Under the joint sponsorship of the Transportation Research Board and the U.S. Department of Transportation (with NASA participation) under NASA Grant No. NGR 47-005-181.

- (1) Define the scope of the area;
- (2) Identify the major technology gaps in the area;
- (3) Identify specific problems for each major gap;
- (4) Whenever possible, rate the priority of each problem;
- (5) Comment upon the contributions which might be made by TRB, and the need for a continuing committee to provide a focus for the TRB efforts.

Participation was by invitation and the participants are listed in Appendix B, first alphabetically and then by discussion group. The Department of Engineering Science and Systems of the University of Virginia agreed to provide a participant for each group who would serve as recorder for that group, and prepare a digest of the conclusions reached by that group. The major body of this summary report is thus a collection of these group reports, with minor editing to provide continuity.

Before presenting these reports, it is well to outline briefly the technical approach that was used to define the groups and their areas of responsibilities.

TECHNICAL APPROACH

The overall problem of the evaluation and/or prediction of passenger acceptance of existing or proposed transportation systems, as viewed by the Task Force on Ride Quality can be represented by the schematic system flow chart of Figure 1. Three basic transfer functions are required, and the workshop was designed around the study of these three functions.

1. The Vehicle Transfer Function³

This function accepts the inputs to the vehicle from the environment within which it operates and, imposing these inputs upon the design and operating characteristics of vehicles, generates as an output the motions to which a passenger in the vehicle will be subjected. Thus the concern here is both with defining the proper nature of the inputs which the vehicle can be reasonably expected to encounter, and with understanding how the vehicle can be expected to respond to those perturbations under the best conditions of operation.

2. The Passenger Transfer Function

This function accepts the vehicle motion, as well as the other physical environmental variables to which the passenger is subjected, and determines a subjective evaluation of the reaction by the passenger to the ride, based upon a perception of comfort. Again, the concern is with the definition of all appropriate inputs to the passenger (other than motion) and the determination of a quantitative relationship to translate these inputs into an output value, this time the subjective evaluation by the passenger of comfort.

3. The Value Function

A ride may well be of high quality as judged by comfort, but still unacceptable to the passenger, or vice versa. Thus the final step in the evaluation process is to

³A Glossary of technical terms may be found on page 77.

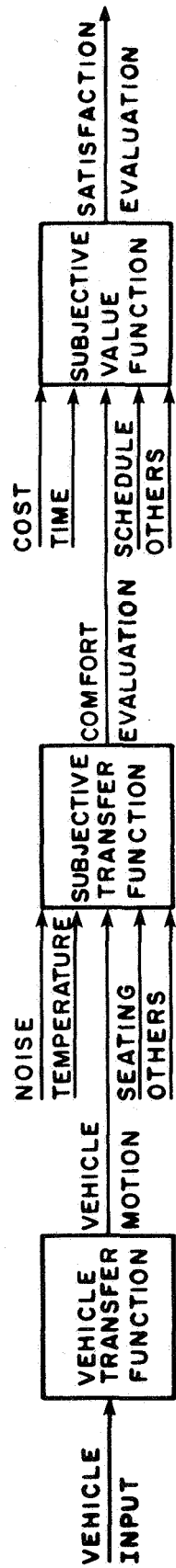


FIGURE 1. THE RIDE-QUALITY "SYSTEM"

combine comfort ratings with other aspects of the operation of a vehicle and the entire transportation system within which it operates, and deduce a relationship which will measure the overall degree of acceptability to the passenger.

It was determined that the working groups should correspond to these three major transfer functions. However, upon further analysis, it appeared as though the body of knowledge associated with understanding the inputs to air and marine vehicles was quite distinct from that required for land-based vehicles. Hence it was decided to form four basic working groups as follows:

Group A - Surface Vehicles

Concerned with the formulation of vehicle characteristics including the description of the appropriate inputs to the vehicle and the vehicle transfer function for all land-based vehicles.

Group B - Air/Marine Vehicles

Responsibility similar to Group A, except that the concern is with aircraft and high-speed marine vehicles.

Group C - Passenger Transfer Function

Concerned with the subjective response of passengers in terms of comfort evaluation including all normal stimuli associated with the vehicle. The group should examine this question for vehicles appropriate to all modes.

Group D - Value Function

Also concerned with a subjective evaluation, this time of overall passenger satisfaction under circumstances where comfort is considered along with other vehicle and system parameters. Again, all modes should be considered.

GENERAL COMMENTS

As indicated in the preface, it is intended that this summary report be primarily a collection of the individual group reports. It is believed that this format will provide the interested reader with the best possible perspective for appreciation of the problems and issues involved. The fact that many topics surfaced for consideration in more than one group, and some in all groups, serves to indicate the crucial status which they enjoy. To attempt to draw overall conclusions on results in a general summary seemed to encourage a risk of at least detracting from the value of the work, and at worst of misrepresenting the true picture.

Nevertheless, there were several factors which emerged from the discussions which need emphasis because of their impact on the scope of the meeting or on the interactions between the areas of interest arbitrarily assigned to the groups. A brief mention of these at this point should be helpful.

- (1) The representation of the ride-quality domain as presented in Figure 1 is oversimplified. It was clear from the deliberations of the groups that there is feedback of varying degree at every point. The most general type of feedback is that each individual group needs to play an important and early role in characterizing the inputs which it requires. These inputs are, of course, the outputs of the preceding group, who must know what is important to their users so that the research efforts can be properly oriented. A mismatch in this interaction can cause much waste and many delays in achieving improvement in ride acceptance at the operating level.

- (2) It should be emphasized that in all cases it was not the intent of this meeting, nor in general is it the primary concern of the individuals involved, to formulate, agree on, or promulgate criteria for ride acceptability. Rather, the emphasis is upon research and the understanding of phenomena. However, in the ultimate practical application, criteria, or standards, will be required, and so the researcher must keep this in mind and assist whenever possible by the proper orientation of current and future efforts, and by the interpretation of results.
- (3) Another deficiency in the flow chart of Figure 1 is that it is not necessarily true that the only system output occurs at the end of the chart. Actually, the operation of a transportation system is a continual interaction between suppliers and purchasers (both of equipment and services). Certainly, a type of system output is required from each of the vehicle groups to assist in the problem of how to establish proper procedures for certifying contractual performance of a manufacturer as a vehicle is produced. This fact was indeed noted by the vehicle groups. However, it does not appear as explicitly in the other groups. In a sense, the matter does involve issues of "user" acceptance and value judgment, but with inputs quite different than those shown in Figure 1. It would seem fruitful to devote further attention to this general problem to improve its definition and determine proper approaches to solution.
- (4) Finally, there is no unanimity as to how the vehicle operator(s) (drivers, pilots, etc.) should be treated. Some groups chose to restrict their discussions to passengers only while others included

operators. Clearly, the role of the operator varies considerably among the different vehicle types. This relationship is controlled to a large extent by types of environments involved and the roles assigned to the vehicle operators by the current technology used in the vehicle design. The feeling seemed to be that the effect of ride quality on the operator should not be ignored in marine vehicles and buses, and, in the case of a private auto, the driver is simultaneously passenger and "crew." Also, it is difficult to question the premise that the effect of ride quality on operator performance can be an important input to the passenger. However, the factors that may be important in governing ride-quality "acceptance" (if indeed that is the proper term) of the operator are not necessarily of equal importance to the passenger. Thus it would seem that the entire area of the relationship of ride quality to operator should receive much more attention than it now enjoys.

GROUP A - SURFACE VEHICLES

Introduction

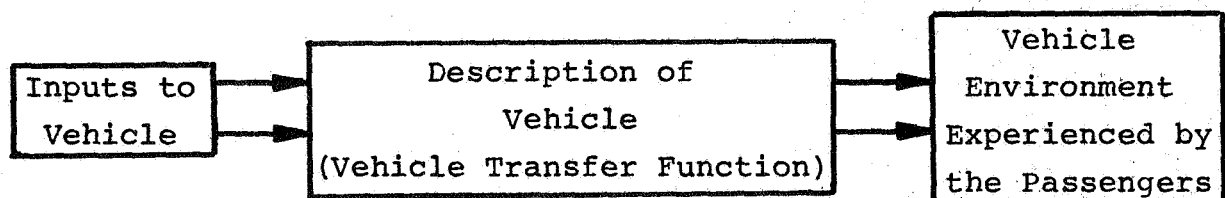
Since the surface vehicle category represents a very large group of vehicles and surface types, it was agreed that two subgroups should be formed following what was felt to be a very natural line of division:

Group A-1 Steel Wheel/Steel Rail Vehicles

Group A-2 Rubber-Tired Vehicles

Thus, the two subgroups are listed separately in Appendix B, and, in fact, spent most of their time in independent meetings. They did, however, coordinate their activities both through a short joint session during the second day, and through continual interchanges between the subgroup chairmen.

Although separate reports are presented for the two subgroups, the general scope of their areas of concern were the same. With reference to Figure 1, the appropriate areas of concern can be illustrated as:



The inputs to the vehicle involve the ability to describe conditions of track and roadway. It is important to emphasize that this must be considered as a dynamic process. For example, the inputs can be a function of the structural properties of an elevated guideway or bridge, the ballast conditions of a track, subsurface conditions of a roadway, the weight and speed of a vehicle, etc.

The vehicle transfer function includes not only the wheel or truck suspension systems, but also such things as the flexural characteristics of the vehicle itself, seating, and other environmental quantities such as noise, temperature, lighting, etc.

The mission of each group is to determine how well the vehicle environment, produced by the coupling of the inputs and the vehicle characteristics, can be specified under a variety of typical or probable operational circumstances. These outputs then represent the inputs to the passenger upon which he or she will make a subjective judgment concerning ride quality.

Report of Subgroup A-1
Steel Wheel/Steel Rail Vehicles

Background

In considering assignments of this subgroup, it became apparent that although it was possible to identify major technology gaps and specific problems within each area and state them in a reasonably orderly generic sense, the magnitude and characteristics of the problems would vary markedly when they were considered from the viewpoint of a specific system operating under specific conditions. Thus the approach in presenting this summary is to address the generic-type issues and suggest that they can be interpreted in the light of the following framework for the definition of a wider variety of more specific problem statements.

A. Vehicles for Intercity Systems

1. Commuter-type
(Commuter is defined as a normal daily two-way trip over a large potential range of distances.)
2. Corridor-type
3. Long-haul type

B. Vehicles for Intracity Systems

1. Rapid transit
2. Light rail

It may also be necessary to add at least two more dimensions to obtain suitably definitive problem statements. One is use orientation: e.g., business vs. pleasure. The other is oriented toward passenger accommodations: seated, standing or reclining; or passenger activities: reading, writing, eating, etc. What this suggests, of course, is that some feedback in the nature of bounds on output descriptors may be required from the study of the subjective evaluation of passengers in order to permit the

gaps and problems in the vehicle area to be defined at the appropriate level for optimal solution.

Technology Area Gaps

The discussions of Group A-1 were structured about three major topics:

- A. Vehicle/Guideway Dynamic Modeling;
- B. Equipment Testing;
- C. System Design Considerations.

The major technology areas related to each of these topics where gaps are felt to exist are outlined below and then each gap area is analyzed separately in more detail in order to define problems.

- A. Vehicle/Guideway Dynamic Modeling
 - 1. Input descriptions
 - 2. Vehicle dynamics
 - 3. Output type and form
- B. Equipment Testing
 - 1. Model verification
 - 2. Data base format
 - 3. Equipment verification
- C. System Design Considerations
 - 1. Design trade-offs
 - 2. Compatibility of criteria

Problem Definitions

(A.1) Description of inputs required for vehicle/guideway dynamic modeling.

- a. Power Spectral Density (PSD) descriptions of guideway inputs are not always adequate for ride-quality work.

The major difficulty arises in the lateral mode and is related to the fact that one is generally

confronted with nonlinear phenomena which PSD does not adequately describe. PSD also provides no phase information, nor any information on discrete events, which are common guideway-related inputs. Both of these latter considerations are very important to ride quality.

Priority: High

Current Effort: Weak

- b. Improved standardization procedures for track classification schemes are needed.

Although a reasonably satisfactory set of classification numbers exist to describe track conditions (FRA track classifications), there is no uniformity in the procedures for implementing classification assignments. Experience has shown that the inputs to be obtained from a given class of track vary widely, seemingly depending on who makes the classification. Thus a researcher cannot make a reliable translation from a track classification number to an input spectrum.

Priority: Medium

Current Effort: Weak

- c. There are a number of specific rail/wheel interaction problems where adequate quantitative description of the forcing function caused by the interaction either does not exist or is not sufficiently standardized. Principal areas are:

- (1) wheel out-of-round;
- (2) lateral coupling between wheel and rail;
- (3) geometric representation of track;
- (4) dynamic representation of track under vehicle loading.

Priority: Medium to high

Current Effort: Weak to moderate

- d. Inputs due to adjacent car coupling are not well understood.

The major effect is in transverse motion and it is especially pronounced at either end of the train. It is less severe on truck-driven vehicles (self-propelled cars). Not only are there problems involved with obtaining an adequate description of the induced motion, but also it is clear that much work needs to be done in the area of coupling design. Effects on longitudinal motion are minimal and usually induced by the operator.

Priority: Medium to high

Current Effort: Weak

(A.2) The modeling of vehicle dynamics.

In general this area has received the most attention and is reasonably well under control. A major question having a large influence on the future effort necessary in this area is that of the level of sophistication which will be required for ride-quality work. Present requirements imposed on the area for other uses do not involve detailed nonlinearities or extensive consideration of flexural modes of the vehicle. Thus these areas are not too well advanced.

Some specific issues which need attention are:

- a. Although new truck designs are generally easier to analyze than the older types, the use of new materials such as elastomers, which have highly nonlinear frictional and kinematic relations, is causing some problems in analysis.
- b. Nonlinear effects of air damping is difficult to handle.

- c. Wheel/rail interface forces such as creep (slippage on a wet rail) are not well understood.

Priority: Low

Current Effort: Strong; in both industry and academic institutions

(A.3) Outputs required for ride-quality work.

It was felt that unless great sophistication is required in the vehicle dynamics modeling (see above), most of the outputs required for ride-quality work can be predicted reasonably well subject to previously-mentioned limitations. The two possible exceptions are noise and pressure. Pressure appears to be a problem only at high speeds when passing nearby objects or upon entering tunnels. Several groups are actively working on the problems associated with high speeds in tunnels. Noise modeling probably will require some work.

- a. Input-output relationships for noise generated by a vehicle do not exist.

Although manufacturers seem to be able to build vehicles to meet arbitrary noise specs, the process is acknowledged to be almost entirely empirical. It is quite probable that the resulting designs are no where near optimal, but the main penalty is probably in excess weight, which is not too much of a problem (except in energy considerations) for tracked vehicles. In order to develop an appropriate program in this area, some feedback is needed as to what is important for the consideration of subjective response problems.

Priority: Low

Current Effort: Weak

- b. The ability to transfer the outputs to a variety of locations in the vehicle needs some attention.

Although it is straightforward to estimate values of variables at any point on the rigid structure of a vehicle based upon observations at a fixed point, an improved understanding of the modeling of seat transmissibility is desirable. Such a wide variety of flexible seating is available that some classification scheme to provide an approximate degree of standardization might be a first step. The significance of the matter is questionable, particularly in view of indications that quantities such as seat shape, size, spacing, etc., are far more important to comfort than is transmissibility. A major problem in this regard is that seating is selected by the system operators for a variety of reasons not related to ride quality.

Priority: Low

Current Effort: Weak

(B.1) Testing for model verification.

- a. A systematic model verification procedure does not exist.

There is very good evidence that the ISO criteria do not reflect subjective judgments. In fact, practical experience suggests that application of ISO standards often predicts the opposite of what is obtained subjectively from in-situ testing. Other criteria, such as W_z numbers as proposed by Sperling, show promise but need further study.

- b. The usefulness of various types of output presentations needs further clarification.

For example, what are the contributions of rms, PSD or peak values toward achieving the ultimate

objectives of ride-quality determination and improvement.

Priority: High

Current Effort: Weak to medium

(B.2) Improved data base.

The existing data base is inadequate. Although large amounts of data are being generated, they are not adequately documented or are not complete. Thus they are often of little value for testing or evaluation purposes. Two specific illustrations are:

- a. Relationships between input and output data are often lacking, e.g., large amounts of vehicle motion data exist which are not adequately related to track profile information;
- b. Relationships between output data and subjective reactions are often lacking, e.g., large amounts of vehicle motion data exist for which no subjective reaction was obtained.

Priority: High

Current Effort: Weak to medium

(B.3) Equipment verification.

The tendency persists to specify equipment performance tests on an as-good-as basis. This approach is often incorrectly applied with results that can be far from optimal in achieving proper performance economically. The problem is that no well-defined alternative exists which has been sufficiently tested to capture the confidence of the market. The solution involves the proper understanding, utilization, and demonstration of the results obtained from many of the other problems outlined in this report.

Priority: High

Current Effort: Weak

(C.1) Inadequate cost data are available to planners and designers in making design trade-off decisions.

Among the areas of significance are:

- a. Costs of track maintenance to various levels of specs. This is complicated by its being a strong function of the types of equipment using the track and the amount of each which must be accommodated;
- b. Costs of maintenance on suspension systems of all types;
- c. Overall costs related to more sophisticated active suspension systems.

Priority: High

Current Effort: Low

(C.2) The relationships between designing for good ride quality and good safety are not well understood.

This can be illustrated by considering the extreme case where sophisticated active controls on suspensions could provide a good-quality, high-speed ride right up to the point of derailment.

Priority: Low to medium

Current Effort: Weak

Recommendations

Subgroup A-1 definitely was of the opinion that there was a continuing role for TRB to play in the general area of ride quality. In reaching this conclusion, the group noted the highly interdisciplinary nature of the problem as evidenced by its discussions as well as its observations of the general composition and tenor of this workshop. Although there are several other associations involved in specific aspects of the

problem, none has the breadth of interest that exists in TRB, and thus TRB is perhaps uniquely qualified to assume a leadership role. This led the group to make the following general suggestions which it considers of major importance.

1. The broad interdisciplinary nature of "Ride Quality" should be recognized by redesignating it "Ride Acceptance."
2. TRB, because of its very broad interests in the field of transportation, can play an important role in the area of Ride Acceptance and should continue to do so.

Specific objectives of TRB participation in this area would include:

- a. Serve as a focal point for exchange of information among workers in the several related fields:
 - (1) through technical meetings and workshops;
 - (2) through publications;
 - (3) through committee activities.
- b. Stimulate transfer of information between the research community and the application or user community:
 - (1) through committee activities and workshops to define the current research needs;
 - (2) by helping relate the interpretation of research results to groups responsible for the formulation of the essential criteria necessary for effective and efficient progress in improving ride acceptance throughout the industry.

c. Assume a responsibility for the identification of the needs and desires of the user community and the general public:

- (1) by inviting and encouraging representatives of these sectors to participate in many of its activities;
- (2) by having its members gather essential inputs from these sectors by individual interactions with appropriate representatives;
- (3) by organizing joint activities with various user-type organizations functioning at the national level.

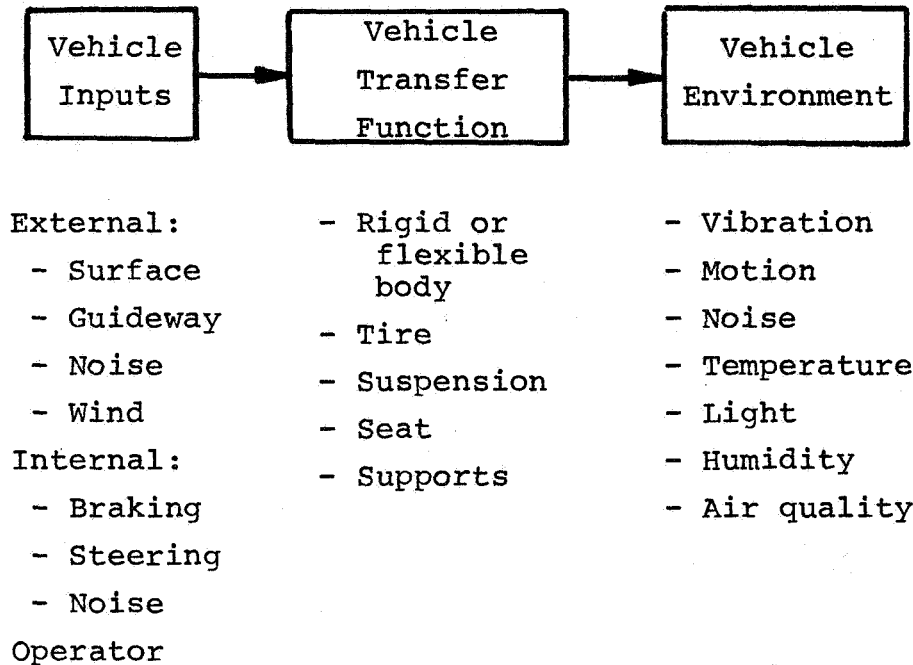
Because of the need for a uniform, well-coordinated effort spanning the various disciplines, the group concluded that a committee dedicated to the broad question of ride acceptance was essential.

Recommendation: That the TRB activities in the area of Ride Acceptance be vested in a new committee charged with responding to the broad interdisciplinary character of the field.

Report for Subgroup A-2
Rubber-Tired Vehicles

Scope of Technology Area

The broad scope of the efforts of subgroup A-2 are illustrated schematically in the block diagram below:



Thus the scope of the areas to be considered was comprised of the following:

- Inputs to vehicle
- Vehicle description
- Vehicle output (passenger input)

After identification of the three broad areas to be considered by subgroup A-2, subsequent discussion suggested that the major effort be devoted to inputs and transfer functions. Further, it seemed convenient to identify specific limitations that would be imposed in subsequent discussion. These additional restrictions of scope eliminated the following:

- temperature
- light
- humidity
- other air quality factors

Hence primary consideration was given to those areas of the input spectra and vehicle transfer function which are associated with:

- vibration induced by normal operation
- responses to driver/guideway maneuvers
- transmission of vibration through seating and other passenger supports
- transmitted or self-generated noise

Consistent with the charge to this working group, consideration was also limited to only those surfaces and vehicles which could be identified and associated with rubber-tired vehicles and concerned exclusively with ground transport of passengers.

Additionally, excluded from consideration were uncontrolled surfaces and associated vehicles such as rough terrain for military application, recreational vehicles (which might include off-roadway vehicles), agricultural vehicles, and general construction equipment.

Thus major emphasis was placed upon surfaces that are typically controlled by man and in which the cost associated with control can be included as a factor in the deliberation. In summary, consideration of vehicle surfaces would be restricted to and identified as controlled, prepared, man-made, and identified with public transportation (including automobiles).

1. Roadway Surface Categories

It was agreed that the following four categories of surfaces included all those that were of major concern to this workshop on ride quality:

- a. Highways (or roadways);
- b. Guideways;
- c. Bikeways;
- d. Automated or guided highways.

Highways were identified as general multiple use surfaces and were distinguished from guideways in that they did not provide direct lateral control of vehicles. This definition of highway category included bridges and elevated sections associated with such roadway surface and is typified by the following types of roads: interstate, U.S. highways, state, county and municipal roads, gravel roads, dirt roads. These were restricted, however, to include only those roads under the jurisdiction of some public agency such as a state highway department, etc., and thus excluded any roadways of a private nature.

Guideways are special-use/special-application surfaces and are designed to provide vertical support and direct lateral control or guidance to the associated vehicle. These will, in general, include supported or suspended vehicles but will exclude metal-wheel vehicles and cable cars. Guideways considered were those in which some public agency provides and controls both the guideway and the associated vehicle.

Bikeways, as used in this discussion, are simply a broader definition of highways and include those surfaces specifically designed and restricted to the use of bicycles and perhaps motorbikes and mopeds. Because of the relatively minor nature of the known ride-quality problems associated with these surfaces and vehicles, these were not given extensive consideration.

Automated or guided highways, while identified as important surfaces, were not extensively considered and discussed because of the unique nature of the vehicle and guideway design, and because of the variety and uncertainty of guideway configurations and designs.

It should be noted that runways and taxiways at airports are included here under the definition of highway and roadway surfaces since the problems associated with runways and taxiways may be similar to those involved in other highway applications.

2. Vehicle Types

Based on what were felt to be the primary objectives and priorities of this discussion, it was decided to consider only those vehicles concerned with the movement of passengers.

Vehicle types were identified as those which would utilize:

- a. Roadways;
- b. Guideways.

Vehicles which use primarily highways or roadways could include:

- a. Automobiles (including taxis, vans, etc.);
- b. Buses;
- c. Trucks;
- d. Motorcycles;
- e. Mopeds;
- f. Bicycles.

Vehicles which use primarily special purpose guideways would include:

- a. Guideway vehicles;
- b. Automated highway vehicles.

In terms of importance, specifically in terms of ride quality and public interest, the following priorities were established for vehicles using highways:

- a. Buses;
- b. Automobile-type vehicles, including passenger cars, vans, and taxis;

- c. Trucks;
- d. Other vehicle types such as motorcycles, mopeds, and bicycles.

No priorities were established under the guideway vehicle category.

3. Passenger Input Characteristics

The two primary characteristics of the vehicle output (passenger input) were identified as:

- a. Motion;
- b. Sound (or noise).

Motion would include such parameters as acceleration, jerk, vibration, and other measures of oscillatory motion up to approximately 80 Hz. Sound would span the 20 to 20,000 Hz frequency range.

Technology Gaps

Rather than focus strictly on technology gaps, it was decided to first identify the major technology areas and then identify specific gaps within each area. Within this approach, the following technology areas were discussed:

- 1. Surface characteristics and measurement;
- 2. Tire-road interface;
- 3. Suspensions;
- 4. Noise isolation;
- 5. Longitudinal control;
- 6. Passenger compartmentalization;
- 7. Measurement and measurement techniques.

Problem Definitions

1. Surface Characteristics and Measurements

This area is concerned with the specific questions of what surface parameters are directly related to ride quality and

what techniques can be utilized to measure these parameters. For example, on roadway surfaces, there is considerable difference between the current roughness index and vehicle-measured roughness such as determined from the GM profilometer. There are also techniques for direct physical measurement of the static profile of the surface. Questions remain as to how the required profile is to be specified.

There is also some question as to the best procedure for measuring characteristics of roads such as settlement, causing surface wavelengths longer than 10 feet. Specifications are needed for these important long-wavelength spans.

Another area relating to road input is that of the dynamic characteristics of surfaces such as elevated roadways and bridges. Currently there are no established standard techniques for determining such characteristics, nor is it known exactly what parameters should be identified and measured as the most significant vehicle inputs.

Another critical question within this broad area of surface considerations is that of specifying requirements for new construction and subsequently, specifying a requirement for maintenance needs. Again, the basic questions are what parameters should be used for identifying a need for maintenance and how these parameters should be used when making the decisions.

Specific Gaps

- a. How to measure (and specify) surface profile characteristics that are significant to ride quality?
- b. How to measure dynamic characteristics of elevated or suspended surfaces?
- c. What parameters should be used for describing surface characteristics?

- d. What parameters should be used in specifying designs?
- e. Development of surface input model.

Importance: Essential, if surface is to be made a part of ride-quality definition.

Current Effort: Substantial, but not directed specifically at those problems listed.

2. Tire-Road Interface

The dynamic interaction between a rubber tire and a roadway surface certainly has a strong influence on resulting vehicle motion and input to the passenger. While there is adequate technology for designing tires to give whatever comfort characteristics can be described, the specific parameters to be used in specification are not clear. In addition, the cost of developing such tires may be prohibitive.

In terms of developing a vehicle model, the dynamic characteristics of the tire, not only vertically but also laterally, should be specified.

Specific Gaps

- a. To what extent does the dynamics of the tire-road interface influence vehicle output?
- b. What are the significant physical parameters in defining tire response?
- c. What should be the design specifications to achieve desired response?
- d. What are the desired response characteristics of an optimum tire?

Importance: Further knowledge desirable, but heavily dependent on cost.

Current Effort: Negligible.

3. Suspensions

This area includes the vertical suspension system and the lateral suspensions used for guidance. Both active and passive systems were considered for each type of suspension system.

While there are claims for a preference of one type of suspension over another, there is little analytical data on which to compare types; e.g., solid axle vs. independent suspension. Also, the maintenance requirements of suspension systems are of concern since there are trade-offs between cost of capital and maintenance, and resulting ride quality.

Roll response may be a significant characteristic of a vehicle, particularly when the center of gravity is far above the roll axis of the suspension system.

Positive lateral guidance and steering controls used on vehicles in guideway systems may have a significant input through the suspension system to the passenger compartment.

It is possible that the entire area of lateral guidance should be identified as a separate technology area since the problems associated with this area and with the corresponding gaps in technology are somewhat distinct from general suspension systems.

Specific Gaps

- a. Development of a better analytical model to represent vehicle suspensions.
- b. Current lack of lateral and longitudinal capability in suspension modeling.
- c. Identification of significant parameters to describe the influence of suspension on ride quality.
- d. Need for experimental baseline or reference.

Importance: Desirable, although significant information is available from previous research.

Current Effort: Negligible, but only because extensive prior research has made possible adequate modeling of suspension systems.

4. Noise Isolation

Topics that need to be considered include the sources of sound, control techniques, and the corresponding trade-offs in terms of cost vs. noise control.

Specific Gaps

- a. What are the acceptable level and quality of sound?
- b. Should specifications be in terms of frequency, db level or what?
- c. How can a system be designed for specific sound requirements?
- d. Need to establish broad noise control methodology for design.

Importance: Desirable, although there is little evidence to indicate that noise is currently a significant problem in ride quality of rubber-tired vehicles.

Current Effort: Modest in those areas outlined above.

5. Longitudinal Control

This area has been given very little consideration compared to other degrees of motion. Under this broad area would be included factors affecting longitudinal motion such as the propulsion system, braking characteristics of automated vehicle control, and nontechnical aspects such as driver input to buses and other passenger vehicles.

Specific Gaps

- a. What is the relationship between degrees of braking and resulting longitudinal motion?
- b. Role of driver input (starts and stops) on resulting ride quality.
- c. Consideration of driver training as a legitimate parameter in ride quality.
- d. Can (and should) longitudinal motion be controlled to limit accelerations?

Importance: Highly desirable, since longitudinal motion on most rubber-tired passenger vehicles is most bothersome.

Current Effort: Negligible; research efforts needed.

6. Passenger Compartmentalization

One possible avenue for the improvement of ride quality in all vehicles is the appropriate treatment of the passenger through compartment isolation and through improvement of the passenger area in present vehicles.

Specific Gaps

- a. Identification of standards for design of both seated and standing passengers.
- b. Characteristics and form of supports (longitudinal and lateral) for standing passengers.
- c. How should input to seated passengers be divided between the feet and the seat?
- d. What are specifications for seat design and seat comfort?

Importance: Desirable, especially for public transportation vehicles such as buses.

Current Effort: Limited.

7. Measurement Capability

In all of the previous areas, the questions always finally come back to the basic issues of what type of characteristics should be specified for ride quality; how can these characteristics be incorporated in the design; and subsequently measured to ensure the design meeting specifications.

- a. What characteristics should be used; should it be rms acceleration, the ISO standard, some kind of weighting formula, or some other approach? There appears to be no satisfactory method at present.
- b. How should vehicles be accepted? What are the specifications of the test to qualify vehicles.
- c. There is still no adequate specification for longitudinal motion. Neither rms acceleration nor peak acceleration appears suitable but perhaps some combination would be adequate.
- d. Finally, what is the standard for ride quality? Perhaps it should not be an absolute standard but some type of relative measure. Nevertheless, some objective standard is still needed although automobiles are currently accepted on the basis of the feel of individual drivers.
- e. Specifications for roadway and vehicle design should be considered together since it is this combination that determines input to the passenger.

Specific Gaps

- a. What are requirements for jerk or acceleration in longitudinal control and how can these be measured?
- b. What should be the peak g-level for isolated transients (i.e., resulting from potholes, switches, etc.)?

- c. What are the guidelines on total rms acceleration in the frequency domain?
- d. How should frequency peaks be handled?
- e. Establish standard test configurations.
- f. What is the optimum location for sensors?

Importance: Essential.

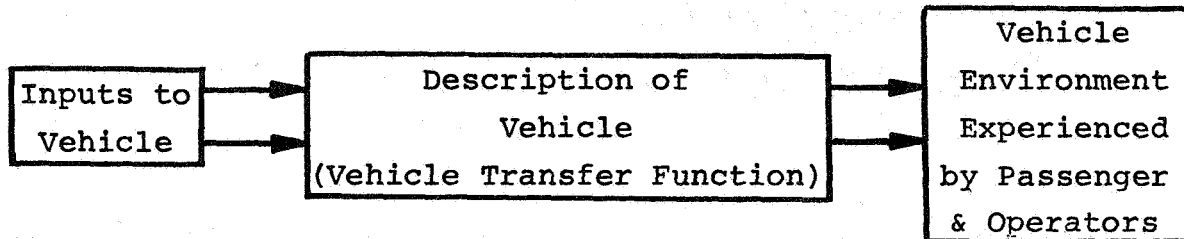
Current Effort: Limited.

TRB Involvement

Subgroup A-2 answered the question of whether TRB should be directly involved in ride-quality activities with a unanimous YES. TRB would provide a focal point for the concentration of activities, for improved communication, for dissemination of information and as an outlet for reported work in the area.

GROUP B - AIR AND MARINE VEHICLES

Scope of Technology Area



As the above figure illustrates, the scope of effort this group addressed is comprised of three components:

- A. Inputs from the environment to the vehicle;
- B. Vehicle description, to include pilot in the loop;
- C. Vehicle output, in the form of the environment experienced by the crew and passengers.

Within these three main areas, specific items as outlined below were identified for detailed evaluation.

A. Inputs to the Vehicle

For both air and marine vehicle systems, significant inputs to the vehicle are often associated with the natural environment (e.g., turbulence, waves) as opposed to surface vehicle systems where the inputs are generally associated with man-made components.

- 1. Input items identified as common to both air and marine vehicles include:
 - a. Maneuvers (vehicle control inputs)
 - b. Noise and vibration (by vehicle and equipment)
- 2. Items identified as unique to aircraft include:
 - a. Atmospheric turbulence, gusts, wakes
 - b. Runway roughness

3. Items identified as unique to marine vehicles include:

- a. Sea conditions (wave description)
- b. Surface winds

B. Vehicle Description

The transfer function which can be used to describe the ride environment resulting from the inputs to the vehicle depends primarily on the characteristics of the vehicle. However, inputs caused by the pilot (operator) in the control loop cannot be neglected. All items identified for this component are common to both air and marine vehicles and include:

- 1. Equations of motion;
- 2. Coefficients of the above equations;
- 3. Pilot-in-the-loop characteristics;
- 4. Noise and vibration transmission;
- 5. Active controls.

C. Vehicle Environment

The environment which influences the ride within the vehicle is comprised of factors which include unsteady phenomena, quasi-steady phenomena, and fixed features independent of inputs to the vehicle.

- 1. Factors of the vehicle environment common to both air and marine vehicles include:
 - a. Motions, discrete and random
 - b. Vibrations
 - c. Noise
 - d. Seat characteristics
 - e. Cabin spaciousness
 - f. Temperature/humidity
 - g. Odors (air quality/ventilation)
 - h. Visual cues

2. A factor identified as unique to aircraft is:
 - a. Rate of change of pressure
3. Descriptors for unsteady phenomena--In transmitting data on the vehicle environment to potential users (inputs to passenger transfer functions; design criteria; or contractual specifications), it is important in the case of unsteady phenomena to present the information with the proper descriptors. These include:
 - a. Time histories;
 - b. Exceedance counts;
 - c. Joint probability distributions;
 - d. Spectral content;
 - e. Rms values;
 - f. Peak values;
 - g. Bandwidth;
 - h. Phase relationship;
 - i. Discrete events;
 - j. Exposure duration.

Technology Gap Areas

Evaluation was made of all component items to identify technology gaps. These gaps, listed by component area, are:

- A. Inputs to the Vehicle
 1. Noise and vibration by vehicle equipment;
 2. Atmospheric inputs;
 3. Sea conditions.
- B. Vehicle Description
 1. Equations of motion (for marine vehicles);
 2. Pilot-in-the-loop;
 3. Transmission of noise and vibration;
 4. Active controls (for marine vehicles).

C. Vehicle Environment

No gaps were identified, either in techniques for measurement of any of the factors, or in their interpretation as descriptors for ride comfort models or contractual compliance.

Problem Definition

In this section each technology gap will be discussed independently in accordance with the following considerations:

- Definition of specific problems in each technology gap
- Evaluation of the importance of the problem to the real world (3 point scale: essential; useful; questionable)
- Evaluation of the effort currently underway (3 point scale: major; minor; little or none)

(A.1) Noise and vibration input by vehicle and equipment.

Information is needed on inputs from the following sources:

- a. Propellers;
- b. Reciprocating engines;
- c. Gearboxes;
- d. Auxiliary equipment.

Importance to Real World: Essential for general aviation aircraft, STOL, and helicopters; useful for other vehicles

Current Effort: Minor in all areas

(A.2) Atmospheric inputs.

A large amount of information exists on a macroscopic level. For example, descriptions are available for the

probable distribution of inputs resulting from turbulence as stratified by general classes of terrain, altitude, and season of the year. However, it is difficult to do this on a more microscopic scale. Also good mathematical descriptions for special local phenomena do not exist. Thus the specific needs are:

- a. To statistically define inputs at a local level (for example, on a route between point A and B at a particular altitude);
- b. To define vortices (conditions, characteristics, etc.) at altitude;
- c. To define and predict local wind shear conditions;
- d. To define the random, intermittent nature of atmospheric turbulence.

Importance to Real World: a - Useful
b - Questionable
c,d - Useful

Current Effort: Minor in all of above problems

Comments and Suggestions

- a. One suggestion to improve on the statistical descriptive nature of turbulence for small scale local areas was to involve aircraft operator participation to manually record (using survey sheets) conditions and severity of turbulence for their aircraft type and operating condition.
- b. The following question was then raised:

Assuming that the ability to predict environmental conditions within small local areas existed, what then could be done with it?

Two examples were used to answer this question:

- (1) Assuming knowledge of the transfer functions (given information on a particular route and

customers), what would be the costs and benefits of improving a given aircraft's ride quality (for example, by means of a ride smoothing system)?

i.e., How much increased acceptance for what increased cost in equipment and operating expense?

- (2) This type of information could also be used to predict the impact of particular operating procedures on system acceptance. (For example, on route A to B in aircraft X, should we fly at 3000' or 5000' to produce the most acceptable ride for least cost?)

(A.3) Sea condition definition and prediction.

Extensive data banks exist which catalogue the historic occurrence of sea conditions for the Northern Hemisphere and for major portions of the Southern Hemisphere. These data breakdown into areas of $2\text{-}1/2^\circ$ longitude by $2\text{-}1/2^\circ$ latitude. Similar data are also available for inland seas such as the Mediterranean, North and Baltic Seas, Sea of Japan, Gulf of Mexico, etc. However, the data base is quite sparse in local waters close to land masses where local shoaling, currents, and wind sheltering significantly alters the sea conditions from those that would be encountered in the open sea.

Thus specific problem objectives can be defined as:

- a. To improve the capability to define and predict wave description on a local level in the presence of:
 - (1) currents;
 - (2) shoaling;
 - (3) other local effects such as wind sheltering.

- b. To develop a simplified, standard family of sea conditions for design purposes.

Importance to Real World: a - Very useful
b - Useful

Current Effort: a - Substantial
b - Minor

(B.1) Equations of motion for marine vehicles.

Specific problems which exist for some types of marine vehicles are:

- a. Lack of experimental validation of models of air cushion vehicles (ACV's) and surface effect ships (SES's).
- b. Form of equations inadequate for large motion discrete events (broaching and slamming modes).

Importance to Real World: a - Essential
b - Very useful

Current Effort: a - Substantial
b - Minor

(B.2) Pilot-in-the-loop effects.

The major problems involve identification and modeling of the effects of noise, vibration environment, and exposure duration on the following:

- a. Neuromuscular lags;
- b. Pilot gain;
- c. Pilot leads and lags.

Importance to Real World: May be useful in high-speed ships and general aviation aircraft; minor to questionable use in other vehicles.

Current Effort: Little or none

(B.3) Identification and prediction of noise and vibration transmission paths.

The specific problems in this area involve:

- a. Measurement techniques;
- b. Structural modeling;
- c. Understanding structural damping;
- d. Noise control and treatment techniques.

Importance to Real World: Essential for certain classes of general aviation, STOL, and helicopters; and useful in certain instances in commercial transport aircraft

Current Effort: Minor in all areas

(B.4) Active controls.

The problems in this area are primarily with certain types of marine vehicles. Active control systems for ride smoothing of aircraft have been synthesized and, in a few instances, applied. The few problems which still exist in optimizing various system components are being adequately addressed. The major issue in using these systems is to determine the trade-offs between benefit and cost.

The need for ride smoothing is more easily identifiable in marine vehicles and so the concern is primarily in areas such as:

- a. Active control systems for conventional ships are limited to roll mode. Pitch/heave mode controls are also required for stability;
- b. No one adequate system for air cushion vehicles (ACV's) and surface effect ships exists.

Importance to Real World: a - Very useful
b - Essential

Current Effort: a - Minor
b - Major for surface effect ships

Identification of Potential Sponsor

Without making any effort to assess the current interests of possible sponsors, the group felt that categorical interest could be established for the following sponsors in the gap areas shown:

A. NASA

Gaps: A.1

A.2

B.2

B.3

B. U.S. Navy

Gaps: A.3 (possibly)

B.1

B.2

B.4

TRB Involvement

General consensus, yes--to serve in a role of information exchange, mainly on identification of technology gaps, current research, and research results. A modest role was also suggested in the area of integrating and coordinating research from the different transportation modes.

No discussion took place on the problem of ranking research priorities required to fill the technology gaps, other than the rating of the importance and the discussion of the effort currently underway.

GROUP C - PASSENGER TRANSFER FUNCTION

Scope

The group defined its scope to encompass the following four areas:

1. Population - Passengers on journeys

After much discussion both within the group and with Group D, it was decided to include only passengers on journeys, and to exclude vehicle operators including automobile drivers. The reason for this latter exclusion was that automobile drivers introduce concerns such as: automobile handling qualities, controls, instruments, and psychological variables involved in motivation for purchasing a certain type of automobile, which are beyond the intended scope of the workshop. The responses of the driver to a journey are biased by these variables, whereas a passenger can respond more independently to the journey experience, although a unique psychological bias may be present. It is suggested that the TRB committee involved in safety and vehicle operation may be the proper one to consider the problems of the automobile operator. Finally, passengers with special requirements such as the infant, infirm, handicapped, pregnant, etc., were excluded from special consideration.

2. Input - Physical and psychological environments

The physical input to a passenger by a vehicle, due to the environment encountered by that vehicle, is of prime importance. The types of vehicles to be included are (when carrying passengers only):

- a. Rubber-tired, including automobiles;
- b. Rail or track mounted;
- c. Marine craft;
- d. Aircraft.

Special vehicles such as elevators, escalators, walkways, motorcycles, bicycles, pleasure boats, amusements, etc., were excluded from consideration.

The psychological environment involved in a specific journey encounter as well as the psychological characteristics of the individual passenger, as noted previously, will have a potential impact on the evaluation of a given journey. Hence these are within the scope of concern.

3. Transfer Function - Quantitative relationship between input and output

The transfer function is a model which provides the best mathematical relationship between the input to and the output from the passenger. Although the passenger responds actively in a subjective way to generate output judgments in response to input stimuli, mechanically the passenger is treated essentially as a black box. Thus special biodynamic models, involving masses, springs, dashpots, etc., which relate a physical response of the subject to an input are part of this scope only to the extent that they are needed to characterize the passenger's perception of stimuli or physical responses which produce causative (but not injurious) effects on subjective judgment.

Behavioral and physiological objective measures which could influence subjective judgments are considered in the scope. These include such things as task performance, reading, eating, talking, inception of motion sickness, etc.

4. Output - Subjective evaluation

The output is a subjective evaluation of a journey. There was considerable discussion concerning the various methods for measurement of these evaluations or judgments. It was concluded that at this time no universal approach to such measurements exists; semantic scales of various length, scales with

identified end points, magnitude judgments, etc., are all used. Correlations among them are complex and not well understood. Clearly, unity, commonality, and/or correlation processes relating measures are essential.

Technology Gaps

The following major areas of technology gaps are listed, not necessarily in order of priority:

1. Importance of stimuli;
2. Effects of stimulus combinations;
3. Duration effects;
4. Correlations of laboratory and field results;
5. Stratification of transfer function;
6. Measurement of subjective judgments;
7. Determining orientation and activity effects;
8. Determining representative populations.

Specific Problems

In this section, each of the technology gap areas will be examined more closely. The problems which emerge from this scrutiny are presented, often in tabular form, including the relative priorities assigned. In many problem areas, the priorities are different for different modes of transportation, and this is so noted.

1. Technology Gap 1 - Importance of Stimuli

Table I lists the various environmental stimuli and the importance which they were believed to have in passenger reaction in the opinion of the group at the time of the workshop. We are concerned, here, with the importance of the various stimuli of the physical environment as they influence subjective judgments of vehicle ride quality. Clearly, the importance of the various stimuli may be different for different vehicles.

TABLE I. IMPORTANCE OF STIMULI

a. Motion Stimuli

<u>Motion Component</u>	<u>Rubber-Tired</u>	<u>Importance</u>		
		<u>Rail</u>	<u>Marine</u>	<u>Air</u>
Vertical, acceleration & jerk	E	E	E	E
Lateral, acceleration & jerk	E	A	D	E
Longitudinal, acceleration & jerk	E	A	D	D
Pitch, acceleration & rates	D	D	A	D
Roll, acceleration & rates	E	E	A	D
Yaw, acceleration & rates	D	D	D	D

E - *Essential*A - *Advisable*D - *Desirable*b. Other Physical Environmental Factors

<u>Environmental Factor</u>	<u>Importance</u>
Noise	Essential
Temperature	Advisable
Pressure	Desirable
Humidity	Desirable
Odors	Desirable
Ventilation	Desirable
Seating	Essential
Orientation	Essential
Lighting	Desirable

Evaluations of the degree of importance are made in Table I for the motion stimuli, but, because of the limited data which exist in many cases, this is not felt to be possible for the other variables. Thus in part b of Table I, the environmental factors receiving the highest ratings are considered to be the most important in general to the development of proper transfer functions. It is recommended that future studies should concentrate on measuring environmental factors in the order of the importance given.

The types of measures used for the motion and noise stimuli are listed in Table II. Again, the importance listed indicates the judgment of the group on the value of the measure for development of good transfer functions.

2. Technology Gap 2 - Combinations of Stimuli

The second major technology gap relates to the effect of combined stimuli on subjective judgments. The opinions of the group are summarized in Table III, where evaluations are given for the importance of understanding certain combinations among the motion values, and of adding other environmental values to the motion. A general impression is also given of the current level of effort to establish the significance of the factors, and of the need for future research in the area.

3. Technology Gap 3 - Duration Effects

The next technology gap is knowledge of the influence of the duration of the journey on the subjective evaluation of that journey. The group felt that the evidence available in this area led to conflicting conclusions and that a continued effort was essential. Table IV summarizes the position of the group in this area.

4. Technology Gap 4 - Correlation of Laboratory and Field Studies

There is no question but that laboratory simulators offer much better opportunities for control over experiments

TABLE II. MEASURES OF STIMULI

<u>Motion Measures</u>	<u>Importance</u>
Weighted rms (including weight $\equiv 1$)	Essential
Motion Frequency Content (including D.C. components): 0 - 25 Hz	Essential
25 - 60 Hz	Useful
Impulse Signature	Advisable
Input Location (cabin location, floor, seat, etc.)	Essential
Exceedance Counts and Level-Crossings per unit time	Desirable
Phase Information	Essential
Crest Factor	Advisable
<u>Noise Measures</u>	<u>Importance</u>
dbA	Essential
Pure Tone (when important)	Desirable
Low Frequency (< 100 Hz when applicable)	Desirable
Spatial Variations	Desirable

Descriptors (in order of decreasing importance)

Essential
Desirable
Advisable
Useful

TABLE III. SPECIFICATION OF COMBINING STIMULI AS THEY
RELATE TO SUBJECT JUDGMENT

<u>Motion Factors</u>	<u>Importance of Issue</u>	<u>Current Effort</u>	<u>Possible TRB Contribution</u>
Combining Frequency Effects	Essential	Major✓	Medium
Combining Axes Effects (including rotational degree of freedom)	Essential	Minor✓	High
Corrections for Narrow Band/ Impulse Effects	Useful	Little✓	High*
Sustained Accelerations	Useful & Essential for specific subjects	Little✓	High*
<u>Noise</u>	<u>Importance of Issue</u>	<u>Current Effort</u>	<u>Possible TRB Contribution</u>
Combining Effects of Noise Stimuli	Essential	Minor✓	High*
Fundamental Noise Levels	Useful	Major	Low
<u>Other Physical Variables</u>	<u>Importance of Issue</u>	<u>Current Effort</u>	<u>Possible TRB Contribution</u>
Combining Effects (temperature, humidity, pressure, ventila- tion, lighting)	Useful	Little✓	Low

* - Mode dependent

✓ - Important to continue

Descriptors (in order of decreasing importance)

Essential

Desirable

Advisable

Useful

TABLE IV. EFFECTS OF JOURNEY DURATION

<u>Factor</u>	<u>Importance of Issue</u>	<u>Current Effort</u>	<u>Possible TRB Contribution</u>
Understanding Duration Effects	Essential	Little [✓]	High
Integration of Varying Amplitudes, Directions, and Frequencies of Stimuli Over Duration	Essential	Little [✓]	High

[✓] - Important to continue

than do field tests. However, the relationship between knowledge thus obtained and reactions of paying passengers under similar conditions in the field is not yet completely established. The two main facets of the problem are summarized in Table V.

TABLE V. COMPARABILITY OF LABORATORY AND FIELD DATA

<u>Factor</u>	<u>Importance of Issue</u>	<u>Current Effort</u>	<u>Possible TRB Contribution</u>
Determining Relationship and Applicability of Laboratory Data to Field Situations	Essential	Minor [✓]	High
Determining Relationship of Captive (Laboratory) Subjects to Paying Passengers in the Field	Essential	Little [✓]	High

[✓] - Important to continue

5. Technology Gap 5 - Stratification of the Transfer Function

This technology gap relates to a knowledge of factors which are specific to an individual passenger that will influence

subjective judgment concerning a journey. These factors may either be inherent to the passenger or may represent some special situation which influences the passenger at the time that judgment is required. These factors are evaluated in Table VI. The group felt that the psychological and situational factors are of the greatest importance and need continuing effort.

TABLE VI. KNOWLEDGE OF VARIABLES WHICH
STRATIFY TRANSFER FUNCTION

<u>Factor</u>	<u>Importance of Issue</u>	<u>Current Effort</u>	<u>Possible TRB Contribution</u>
Determine the Influence of Physical Parameters (anthropometric, somatotype)	Useful	Little	Low
Demographic	Useful	Minor	Low
Psychological, Aesthetic	Essential	Little✓	Medium
Situational (standing, seating, lying, activities, crowding, facilities, service, etc.)	Essential	Little✓	High*

* - *Depends on mode*

✓ - *Important to continue*

6. Technology Gap 6 - Measurement of Subjective Judgments

Although considerable effort has been devoted to the study of various methods of measurement, no basic effort has been made to correlate the various methods or to unify them for common utility. At present many investigators continue to use their own favorite measures. Unless it is possible to establish a firm basis for correlation between them, the broad base of data that is currently being obtained from many sources may be fragmented and of limited utility. Table VII presents the group's concerns and recommendations. The use of objective measurement is suggested as supplemental to the subjective

evaluations which are considered to be of prime importance. To be useful, a correlation must exist between the two.

TABLE VII. METHODS FOR MEASURING SUBJECTIVE JUDGMENTS

<u>Factor</u>	<u>Importance of Issue</u>	<u>Current Effort</u>	<u>Possible TRB Contribution</u>
Scale Selection for Subjective Judgments	Essential	Major	High
Objective Measures (behavioral and physiological)	Useful	Minor	Low

7. Technology Gap 7 - Determination of Orientation and Activity Effects

This technology gap relates to the specific problem of passenger body and seat orientation and posture. There are some strong mode-dependent aspects relating to such cases as standing and side-facing passengers on trains and buses. Clearly, such factors can have very important influences on subjective judgment. Table VIII summarizes the group's position on this subject.

TABLE VIII. SITTING VS. STANDING RELATIONSHIPS
(INCLUDING POSTURE AND ORIENTATION)

<u>Factor</u>	<u>Importance of Issue</u>	<u>Current Effort</u>	<u>Possible TRB Contribution</u>
Determining and Understanding the Differences and Influences	Essential*	Little [✓]	High*

* - Depends on mode

✓ - Important to continue

8. Technology Gap 8 - Determining Representative Populations

The last area is concerned with methods of identifying a population that represents the typical passenger groups likely to use specific modes of transportation. It is essential that data sources be properly structured when test subject groups are used. The recommendations of the group are summarized in Table IX.

TABLE IX. METHODS FOR IDENTIFYING
REPRESENTATIVE POPULATIONS

<u>Factor</u>	<u>Importance of Issue</u>	<u>Current Effort</u>	<u>Possible TRB Contribution</u>
Identification of Typical Subject Group Representative of User Population	Useful	Minor	Medium
Sampling Procedures	Useful	Major	Low
Experimental Design	Useful	Major	Low

Funding Sources

The final assignment to the group was to indicate the potential availability of funding for the research suggested as important. Since members of the group were not representative of any particular cross section of funding agencies, and were by no means privy to knowledge of future funding plans, the only logical approach is to identify those sources considered as generally appropriate for certain types of research support. Table X relates these potential sources to the major technology gaps discussed previously.

TABLE X. APPROPRIATE FUNDING SOURCES

<u>Technology Gap</u>	<u>Source</u>
Priority of Stimuli (Some stimuli have a common importance to all modes of transportation, other are mode dependent)	Agencies that regulate and/or operate specific modes of transportation
Combining Effects of Stimuli	(as above)
Duration Effects	DOT and NASA
Laboratory vs. Field Data Comparability	National Science Foundation, DOT, and NASA
Knowledge of Variables which Stratify Transfer Function	(as above)
Methods of Measuring Subjective Judgments	(as above)
Sitting vs. Standing Relationships (including posture and orientation)	Mode associated agencies
Methods for Identifying Representative Populations	HUD

Potential for Contribution by TRB

In discussions regarding the manner in which TRB could contribute to the solution of specific problems, it was felt that the means available were the formation of a working group, and the dissemination of technical information through publications and/or sponsorship of meetings. It was felt that for many of the problem areas, a TRB working group could contribute greatly, not only as a forum for workers in the area but as a link between the user community and researchers as well as a link between both groups and the international community.

The ratings (high, medium, low) provided for each problem area assess the potential for TRB to serve as a catalyst to help in the solution of these problems where needed. A low rating implies either little or no contribution is seen or none is needed.

GROUP D - VALUE FUNCTION

Editor's Note: Since background material on value functions was not specifically identified in the report of the 1975 workshop held at Williamsburg (see footnote 1, pg. 1), an introductory section containing a brief general discussion of system acceptability is included in the report of this group.

General Discussion of System Acceptability

1. Scope

The target population is the set of all potential passengers of transportation systems. Operators will be included in cases such as the auto where the role of the individual is ambiguous or dual.

2. What Features of Transportation Systems Influence Users or Potential Users?

A. What determines acceptability and how?

Inputs to the passenger which influence how acceptable he finds a vehicle include:

- (1) Motion characteristics; comfort;
- (2) Other aspects of the physical environment, including personal space;
- (3) Perceived safety and security;
- (4) Services, amenities;
- (5) Utility, mobility, and activities;
(Utility is meant in the strict sense of economic utility.)
- (6) User characteristics;
 - a. Needs
 - b. Situation, including demographic variables
 - c. Perceptions
 - d. Attitudes, values, habits

B. How does one assess acceptability as an output variable?

We are interested in the acceptability of a system to potential users and how the features of the system affect their choices. Information about various features was seen as processed at two levels: one of which is described by a threshold model, the other by a choice model. In order for users to consider a system, they must find it acceptable on its various features. Unless an acceptability threshold is exceeded on all relevant factors, a person will not use that mode of transportation. Only those transportation systems which are above threshold on all relevant factors enter the choice set. Then a choice model is needed to describe how the person decides which mode of transportation to use; i.e., how does a person evaluate the relative satisfaction or preferability of the alternatives?

Several choice models were discussed: (1) simple adding and averaging models; (2) elimination by aspects, as proposed by Tversky; and (3) configural or interactive models. The first class of models are too simple; the other two are possible candidates for describing system choice.

There are three levels of concern of a user in relation to a system. The system needs to be (1) available, (2) acceptable, and (3) preferred to be used.

Availability is really a matter of geography, location, and other factors, not a technology gap. Technology gaps exist in assessing the acceptability of a single system and in evaluating preference among multiple systems. A set of techniques is needed for assessing acceptability and preference.

The difference was noted between preference and intention, and the often-reported discrepancy between reported intention and actual behavior was reviewed. However, often we must rely on peoples' reports of what they would do, or think they would do, in a given situation. The use of abstract models

are necessary when we study systems that do not exist. We need to know what people think they would do if (1) a special feature were implemented on an existing system which made it different from all other systems, and (2) a new technology was developed. The distinction between (1) upgrading existing systems and (2) developing new systems is necessary. People have a better idea of the impact of the first kind of change. The scenario/situation technique is indispensable for predicting the effects of innovation in transportation systems.

We must analyze why people use various transportation systems and what needs are satisfied by each type of system. The issue of market segmentation and aggregation is crucial here. Different groups of people will have differing needs and expectations for transportation systems, but the best variables to use in segmenting the population of travelers have not been isolated. Market segmentation may be useful in (1) targeting different services at different groups of people and (2) in publicizing the same service in different ways as a function of the needs of subgroups of the population.

Several related topics were discussed involving how people learn about a transportation system:

(1) One suggestion is that a set of descriptors could be developed to provide an indication of the level of service provided by a transportation system. These would be similar to those used in acoustics where various dB levels are described by means of familiar situations in which one experiences that noise level.

(2) Another way to build up service on a system is to provide free tickets or free rides during some time period. One function of this is to make users familiar with the system and its operation.

(3) A third suggestion was to use advertising. Ads may be used to either inform or persuade consumers. They

can disseminate information about a system, induce familiarity with the system, and perhaps create new demand for the system. Very little is known about how people learn about transportation systems.

We need to know the bases for discrimination between systems, and which attributes people fail to discriminate. For example, people perceive no differences among various forms of transportation in terms of system safety, but there are differences in perceived levels of personal security. We need to assess which attributes people use to perceive systems, and what the perceived range of each variable is as well as the actual range of each variable. In particular, what levels define a basic or "no frills" service, and what levels define an unacceptable service? Of the variables which may be altered, what are the costs of doing so?

The role of feeder systems was also discussed. A primary mode may be perceived in terms of its peripheral connections. For example, with a downtown people mover (DPM), there would be little point in improvements of this system if the feeders were so poor as to prevent its use. Does the feeder service ever have to exceed that of the primary line? Or does the primary line determine system evaluation? What improvements on the primary line make a difference? The general issue in all these questions is "what is the interaction between feeder service and the primary service?"

Major Technology Area Gaps

Six major problem areas or gaps regarding passenger acceptance research were isolated:

1. A set of techniques for assessing acceptability and preference of transportation systems;
2. An understanding of how to group or aggregate people;

3. An understanding of how people learn about a system;
4. A definition of the lower bounds on system acceptability;
5. The impact of access modes on overall system acceptability;
6. The relationship between intentions and behavior.

Problem Definitions

Each of the six major technology gap areas are now explored in more detail with specific issues identified in each. A priority rating (A being highest) is given for each and comments are made on work in progress and potential sources of research funding.

1. A set of techniques for assessing acceptability and preference of transportation systems is needed.
(Priority A)

In light of the distinctions between models of acceptability and those of preference, two classes of techniques are required: those dealing with profile data, and those dealing with preference, or dominance, data. In both cases, one can distinguish between methods of gathering data and methods of processing, or analyzing, data. The following set of subproblems can be defined as those where techniques are most needed:

- a. Identification of the possible dimensions or features of transportation systems;
- b. Isolation of the dimensions which are salient to users and potential users, and finding those features that determine acceptability;
- c. Location of threshold (minimum acceptable) levels on each dimension;
- d. Assessment of preferences among acceptable transportation systems;

- e. Isolation of those dimensions used in reaching the preference (choice) decision;
- f. Determination of the rules of combination by which the dimensions yield the preference structure.

Profile (dimensional) data may be generated using: observation, inventories and checklists, expert descriptions, rating scales, passenger comments (and complaints), etc. The analysis of profile data may be accomplished using factor analysis, multidimensional scaling, and clustering schemes. Key references include Harman (1967)*, Green and Carmone (1970), Kruskal (1964), Shepard, Romney and Nerlove (1972), Carroll and Chang (1970), Johnson (1967), and Sneath and Sokal (1974), and Shepard and Carroll (1966).

Preference data is usually obtained by the method of paired comparisons, although ranking, ordering and ratings may also be used. The techniques used to analyze preference data include algorithms due to Thurstone (1927), Slater (1960), and Carroll and Chang (1964), Tucker (1960) and Carroll and Chang (1968).

The means by which a person combines information from several features or dimensions into a single preference judgment also needs to be determined. Possible combination rules include adding and averaging models, configural (interactive) models (Hoffman, 1968), and elimination by aspects (Tversky, 1972). If we know the features of transportation systems that determine acceptability and preference, we gain the ability to predict acceptance and use. The goal is to predict which system changes will result in increased use.

The preference judgments may be obtained for systems

*See List of References at the end of this group report for those citations followed by a date. Citations without a date refer to current work, the results of which are as yet unpublished.

in use, prototype vehicles, and/or scenario descriptions. Behavioral observations and patterns of system use are also necessary.

Work in progress: The Department of Transportation is funding research on two projects related to this topic; one deals with the perceived safety and security of transportation systems, the other with attitudes, values, and preferences toward transportation. Both will involve the use and evaluation of the kinds of techniques described above. Other related projects include Stopher's study of user preferences in Evanston, Illinois, and Pepler and Jacobson's study of passenger perception of bus and train acceptability. Nicolaidis and Richards are also conducting research on this problem.

Funding should be available from both the Federal Government and industry. DOT is especially concerned with this problem area.

As reliable techniques become available, then they must be applied to provide information on the specific issues which are of importance.

2. Grouping or aggregation of people
(Priority A)

Two major issues are involved:

- a. What are reasonable (predictive) bases for aggregation?
- b. What characteristics of people are relevant to their choice of a transportation mode?

Involved here is the individual difference problem in psychology and the market segmentation problem in marketing research. Using perception and preference data, one can identify subgroups of persons having the same cognitive or judgmental structures about the domain of concern. Then, various measures or descriptors are examined to see if they differentiate the groups of people. Useful aggregation of

people for transportation planning will probably involve specifying their needs, uses, and situations. The usual demographic variables are probably only indirectly related to these.

Techniques used in aggregation research include three mode factor analyses (Tucker, 1966), individual differences scaling (Tucker and Messick, 1963; Carroll and Chang, 1970), discriminant analysis (Tatsuoka, 1971), and canonical correlation.

Work in progress: Transportation studies involving the aggregation issue have been conducted by Stopher, Nicolaidis, Myers, Richards, and Pepler. Irwin Levin (1976) and Foerster, Young and Gilbert (1975) have also explored individual differences in perception of transportation alternatives.

Funding should come from both government and industry sources.

3. Learning about a system (Priority B)

What are the roles of experience, the mass media, and advertising in shaping a person's image of and attitudes toward a transportation system?

The basic issue of how one learns about transportation systems has been largely ignored, or at least such studies are not readily available. Clearly, people may learn through direct experience with a system; however, the question of how people assess systems they have no experience with is more crucial. The nature and influence of vicarious (indirect) experience on image and attitude formation has been studied mainly by advertising and marketing research groups.

Work in progress: No work has been done at the behavioral level.

Government funding is unlikely, although UMTA is said to have a contract out to Grey Advertising on this issue. NSF's dissemination of information program or their RANN program might provide funds. Industry is more likely; perhaps APTA, AMTRAK, etc.

4. Lower bounds on system acceptability
(Priority B)

What constitutes a basic ("no frills") system?

Not much prior research has been done on this topic. There are several situations in which one could gather data on passenger reactions to lower levels of service: (1) some U.S. airlines run a night coach service; (2) London downtown buses (British Red Arrow service) run with most passengers standing; (3) European train service includes second and third classes. Scenario simulation techniques could also be useful here.

This area is touchy, but is researchable. In particular, trade-off studies could be done pitting reliability vs. creature comforts vs. costs, or level of service vs. level of comfort, or other similar sets of factors.

Funding: DOT; manufacturers, operators.

5. The impact of access modes on system acceptability
(Priority B)

How does the primary line interface with feeder modes?

A great deal of research is needed here. Only a few studies have been done, but they indicate that the feeder/main line interface is very important to the passenger. A study at Northwestern found that the reliability of the access mode was more important to users than the reliability of the line mode. On the British rail service, users value transit time on access modes at about 2-1/2 times the main trip duration. Stopher, Nicolaidis, and P. Watson have studied perceived times and costs on access and primary modes.

Funding: This area is a major problem. Nobody accepts responsibility for it. It concerns intermodal problems, and no one agency seems to have enough money available. Possible sources include OST, EPA, UMTA, and DOT's advanced transportation research projects program.

6. The relationship between intentions and behavior
(Priority A)

This problem has been studied by learning theorists and cognitive psychologists in laboratory situations. In this setting, intentions predict behavior very well. Dulany (1968) has summarized some of this research. Fishbein and Ajzen (1972) have shown how attitudes predict intentions, and suggest some qualifications on the intention/behavior relation.

A great deal of research is necessary in the real world context. Mary Stearns at TSC in Cambridge is doing one study; Stopher and Nicolaidis also have work in progress. The DOT safety and security and attitudes and values procurements will also address this issue.

Funding is available from DOT, perhaps NSF, and advertising agencies. Much research done in University departments of psychology addresses this issue.

Role of TRB

Ride-quality information is necessary for transportation planning and evaluation. It is important to be able to predict the acceptability of features of new systems and of transportation innovations. A decision to upgrade a system or to plan and design new ones should include an assessment of the ride-quality implications of the change. Ride-quality information may help determine the viability of an innovation.

Investigators from a variety of fields (including engineering, psychology, transportation planning, and marketing) are involved in ride-quality research. These individuals need a single forum

in which to interact, and a TRB committee would be an ideal vehicle to furnish such a forum. As a research area, ride quality will be around for some time; thus some TRB effort would be appropriate.

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GLOSSARY

- active controls. . . .a system which senses motion of a body relative to predetermined null point, and attempts to maintain the null position by generating appropriate forces to be applied to the body to counteract the motion.
- air damping. . . .using compressed air as a medium to absorb the energy inherent in oscillatory motions, thus causing the motions to disappear.
- Airtrans. . . .automated guideway system serving the Dallas/Fort Worth Airport complex.
- ballast. . . .material, usually crushed stone, used to hold railroad tracks in place.
- bandwidth. . . .range of frequencies contained in a given motion.
- BART. . . .Bay Area Rapid Transit, San Francisco, California.
- broaching mode. . . .veering suddenly into the wind.
- canonical correlation. . . .a measure of the degree of inter-relationship between two sets of variables; technically, the maximum obtainable correlation between a linear combination of a set of predictor variables and a linear combination of a set of criterion variables.
- commuter-type rail. . . .intercity service exhibiting the characteristics of providing daily two-way trips over a large potential range of distances, e.g., Penn-Central and New Haven service to New York City from New Jersey, Westchester and Connecticut, Southern Pacific service to San Francisco from the Peninsula.
- corridor-type rail. . . .intercity service through relatively heavily-developed areas; generally less than 300-500 miles, e.g., New York-Washington, St. Louis-Chicago, New York-Boston.

dashpots. . . .devices to provide damping to motion.

db. . . .decibel, a unit of measure of sound intensity or power level.

discrete events. . . .events which take place independently and usually over a short span of time.

discriminant analysis. . . .a statistical method for finding the best way to differentiate between several groups on the basis of linear combinations of a set of predictor variables.

exceedance counts. . . .number of times a variable exceeds some chosen level in some unit of time.

factor analysis. . . .a set of techniques for determining the dimensionality of a set of variables, usually by finding the rank of the matrix of intercorrelations among the variables.

flexural modes of a vehicle. . . .motions of the vehicle structure about a set of axes fixed in the vehicle.

g-level. . . .amount of acceleration referred to the acceleration of gravity.

heave. . . .a complex motion usually combining pitch with a vertical and longitudinal movement of the center of gravity.

impulse signature. . . .waveform representing the impulse.

individual differences scaling. . . .a set of algorithms for isolating distinct perceptual viewpoints about a set of stimulus objects from people's judgments about the similarity of those objects.

ISO. . . .International Standards Organization.

jerk. . . .rate of change of acceleration, usually pertains to the longitudinal direction.

lateral direction. . . .in an x, y, z coordinate system, with x oriented in the direction of travel of the vehicle, and z oriented perpendicular to the plane of the vehicle and directed into the supporting surface, the y axis represents the lateral direction.

light rail. . . .using vehicles which operate predominantly on surface tracks within a city or metropolitan area.

long-haul-type rail. . . .intercity service between points separated by distances greater than commuter-type or not exhibiting the build-up characteristics of corridor-type rail.

longitudinal direction. . . .in an x, y, z coordinate system, with x oriented in the direction of travel of the vehicle, and z oriented perpendicular to the plane of the vehicle and directed into the supporting surface, the x axis represents the longitudinal direction.

peak value. . . .the maximum value of a variable.

pilot gain. . . .the degree of magnitude with which a given pilot will respond to motion imparted to the vehicle through external means.

pilot-in-the-loop. . . .the individual driving the vehicle, introducing inputs which impart motion to the vehicle; these inputs can be either random or in response to an attempt to correct a motion resulting from some other input.

pilot leads and lags. . . .the time sequence of the pilot's response to motion imparted to the vehicle through external means.

pitch. . . .rotation about the lateral axis (see lateral motion).

power spectral density (PSD). . . .a measure of the frequency content of the square root of the square of the mean amplitude of a motion.

profilometer. . . .an instrument for measuring the smoothness or surface irregularities of any surface.

rapid transit. . . .subway or elevated guideway systems, operating primarily within a city or metropolitan area, e.g., BART, NYC subway, Airtrans.

roll. . . .angular motion about an axis in the direction of travel, i.e., the x axis in the coordinate system adopted in this report (see longitudinal motion).

rms. . . .root mean square of a variable, i.e., the square roots of the square of its mean value.

seat transmissibility. . . .the effect which a seat has on transferring motion from the floor (or structure) of a vehicle to an individual in the seat.

slamming mode. . . .sudden impact when part of a vessel is raised out of the water by wave action and then drops to the surface again.

spectrum. . . .the distribution of the values of any quantity.

STOL. . . .short take-off and landing aircraft.

suspension. . . .the mechanism by which the vehicle body is connected to the wheels.

three mode factor analysis. . . .a technique developed by Ledyard Tucker for analyzing data matrices that vary in three ways, or modes. For example, one might have a set of economic statistics (variables) for each of several types of institutions in cities of several sizes.

tracked vehicle. . . .vehicle riding in a track.

transfer function. . . .a mathematical means for computing the outputs to be expected from an object subjected to known inputs.

transverse direction. . . .in an x, y, z coordinate system, with x oriented in the direction of travel of the vehicle, and z oriented perpendicular to the plane of the vehicle and directed into the supporting surface, a transverse direction would be somewhere in the yz plane.

TRB. . . .Transportation Research Board.

truck. . . .the wheel-carriage on a rail vehicle.

vehicle input. . . .the inputs to the vehicle from external sources; e.g., road roughness, track irregularities, winds, turbulence, sea state, etc.

vertical direction. . . .in an x, y, z coordinate system, with x oriented in the direction of travel of the vehicle, and z oriented perpendicular to the plane of the vehicle and directed into the supporting surface, the z axis represents the vertical direction.

W_z number. . . .an index of ride quality developed by E. Sperling and used by the German Federal Railway. For any axis of vibration, human ratings of ride quality are said to take the value $W_z = 2.7^{10} \sqrt{a^3 F^5}$ where a is the amplitude in cm and F is frequency in Hz. A composite W_{z_g} value may be derived from W_z 's for individual motion segments and noise levels.

yaw. . . .rotation about the vertical axis (see vertical motion).

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